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The Effects Of Global Value Chain Participation On Carbon Emissions: Unleashing The Sustainability Aspect And Pathway To Sustainable Trade. (2000-2020)

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Abstract
This study adds to knowledge by investigating the effects of Global Value Chain Participation (GVCP) and Carbon emissions (CO_2) between the years 2000 and 2020 from Input-Output tables available on the World Bank's Database for economic actors. As the world today is interconnected through trade, there is a paramount need to evaluate the rising negative environmental implications. In this essence, this paper contributes to demonstrating a solution against unsustainable trade practices. The data for GVC Participation for each country and industry has been derived from the Export Decomposition Method. Raw data used for GVC participation is taken from the OECD-ICIO database. The main findings of this paper show that the coefficient for GVC participation is statistically significant. The coefficient between inequality and CO_2 emissions highlights the positive relationship between the two variables, indicating that greater economic inequality within a nation is associated with higher CO_2 emissions. Green Energy's negative coefficient of -281.983 indicates a correlation between increased usage of green energy and decreased CO_2 emissions.

Keywords: *Sustainability in trade, climate-responsive frameworks, policy formulations, Global Value Chain Participation.*

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I. Introduction:

The effects of GVC Participation and Carbon emissions have attracted the attention of various scholars in recent times. By 2030, the United Nations (UN) aims to reduce emissions 45% 2030 and by 2050, the target is to reach net zero. After the 20th Century, the world has witnessed evolutions in trade dynamics. For example, there has been a rise in the number of industries operating, an increase in participation in value chains, an increase in trade negotiation, and interdependency in trade Aklin (2016), Liu (2013). Hence, with the emancipation of global economic trade, the focus of decision-makers, international organizations, and scholars has shifted to questioning its impact on the environment. From recent studies, considerate research demonstrated pathways through econometric calculations serving as a factual basis for the concern for environmental degradation and issues related to climate change. The focus of this paper builds upon clearly stated research gaps from previous studies and fosters a critical analysis of unexplored dimensions regarding this research area.

Jing Wang (2022) has written that prospective research on this topic should "cover more countries and regions over a longer period". The most recent examination regarding emissions and trade is till 2018. (, Jithin et al,2023), (Nadeem,2021). Apart from this, another gap identified from the literature is that while attempting to bridge the gap between the effects of unsustainable trade on the environment, the understanding of sustainability has been neglected in previous research. Culminating from the unexplored areas identified, the focus of this paper is to bring to attention that while attempting to close the gap between current trade practices and the negative effects they create on the environment, the basis of sustainability itself cannot be neglected. After this consideration, an informed policy making can be produced that will be effective in all aspects. To bring about sustainable development in trade, there is a need to consider the three dimensions of sustainable development (Peter Glavic et al., 2007). The basic nexus of sustainability encompasses the environment, industries, and society. When enforcing the sustainability principle, all three aspects must be considered. From this understanding, this research contributes to knowledge by demonstrating this neglected factor in previous sustainability studies regarding GVC participation. Jing Wang et al., (2022), stated that for economic growth to prosper, the reduction of CO_2 emissions is critical for sustainable growth. Afeltra, (2022) supports the view regarding understanding the sustainability terminology. Principles of sustainability englobe the three dimensions mentioned above and adhere to such principles in the long term. This research enforces that the social aspect should also be investigated, rather than only focusing on an economically driven objective to produce effective results in the long term (Manupati,2020), (De Vries et al., 2017).

Much focus on this research area has been carried out on the Asian continent by researchers such as (Zhong et al.,2021), (Liu and Meng, and Wang 2023). and (Assamoi et al., 2020). For example, the Belt & Road Initiative countries (Shi et al., 2022). Research has also included developed or underdeveloped countries (Zhong et al., 2021). From the perspective of Wang et al., (2022) the evolving link between GVC participation, CO_2 leakages, and economic expansion has not been fully clarified. The relationship between GVC participation and emissions still demands further investigation. From a global standpoint the extent of participation in GVCs is increasing (Zhong et al., 2021), (Y. Wang., et al 2021). Zhong et al., (2021) provide an analysis from the years 1995 to 2011. Previous scholarly materials depict that economies are emerging and carbon intensity is increasing. From the previous analysis, it is shown that GVCs increased from 2001 to 2008 as a result of expansion in international trade and embodied trade emissions (H. Wang et al., 2021), (B. Meng et al., 2023).

Scholars consent to the fact that emerging economies have contributed to the deepening of trade and markets, however, environmental implications remained fragmented (Golgeci, I., Makhmadshoev, D., & Demirbag, M. 2021) (Fan et al., 2021). The research article by S. Tokito, et al., (2023), argues that the inclusion of environmental guidelines for example carbon tax, disclosing CO_2 leakages, eco-labeling, and supply chain involvement, as part of economic partnership can effectively reduce carbon footprints (J.Wang et al., 2019). According to the WTO (2021) report, an increase in trade emissions is mostly contributed by large economies, sectors including services trade, and transportation.

In analyzing the effects of GVC participation and carbon emissions it is of paramount importance to illustrate the legal framework used as an instrument to enforce protection of the environment regarding these practices. The adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 demonstrated an initiative toward climate action. It was followed by the 1997 Kyoto Protocol (KP), which is the most talked about unilateral environmental regulations for coping with climate change (Peters et al., 2008). The RIO protocol and climate-responsive actions signify common aims of restoring, reducing negative impacts on the environment, and fostering sustainable change. However, as argued by (B. Zhang, 2019), the aims are common but the responsibility to enforce sustainable action differs as responsibility is independent even though legal agreements are binding or non-binding. Hence, it shows the irregularity between what is practiced and what is written on paper. A major understanding coming from the analysis of the author is that it is challenging to compute the emissions' shared responsibility between producers and consumers. This results in issues such as unaccountability and untransparent data on emissions by industries. Given this argument in previous literature, it calls for principles of good governance for ethics, transparency, and accountability in trade emissions regarding trade. The 'good governance' aspect to solve barriers regarding sustainable trade has been neglected and also not stated as a way forward in past literature. Much discussed avenues to solve the issue relate to the inclusion of clean energy technologies in manufacturing industries.

The "Polluter-pays-principle", embraced by the OECD countries in 1974 functions individually, that is, whoever is causing pollution pays damage. It is argued that global efforts to reduce carbon emissions and trade adjustment to generate national responsible emissions accounts can be considered as a complementary policy option to help address the carbon leakage concern (Zhou & Kojima;2010).

Another form of action is the Paris Agreement and the development of renewable energy sources (United Nations, 2015), (Bang, et al.,2016), (Vrontisi et al., 2020). Since the early 1990 international organizations and lawmakers have found that emissions are continuously increasing (Liu & Zhao, 2020). There is consensus around the world concerning the establishment of international treaties, soft laws, policies, international law, national laws, and even regional trade agreements that give attention to addressing this issue. As stated by the United Nations, a 40% to 70% reduction in CO_2 emissions by the year 2050 is the main objective, as well as the introduction of addressing climate change and its effects among 17 Sustainable Development Goals (United Nations, 2022). After such recognition of the drastic effects of CO_2 emissions, it can be seen that there has been a proliferation of international treaties. From this perspective, a detailed study of carbon emissions is emancipating by accounting for its effects on a global scale (Xiaoming Ma et al.,2022). Trade relations between countries have developed and are still increasing creating an easy leeway to transfer emissions in stages of production. Regulations and policies in this area are constantly evolving scholars have increased attention to the effects of GVCs and environmental impacts and policies and the trend is increasing with much curiosity (Xin Zhou & S. Kojima, 2010). An important recent development in international law regarding trade-related wastes is the "Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal" (also known as the Basel Convention) will come into effect in January 2025, by the OECD. Amendments included are to exercise control on the movement of plastic debris and limit plastic waste littering the environment. It should be noted that plastic amendments have entered into force since January 2021. In 2022, "Parties to the Basel Convention", made further agreements to amend controls for e-waste. This new development in international law regarding e-waste created by trade-related GVC activities will enter force in January 2025 (OECD, 2022). Initiatives from international law have led to pathways towards a sustainable future (Gupta et al., 2022). Analysis derived from initial enforcements in legal structures since 1992 and with the continuous enforcement of frameworks in this era till the future signifies the degree of importance and the extent to which policies derived represent that climate change requires immediate attention. The focus set out in this paper does not aim to demonstrate the effectiveness of existing climate-responsive instruments, but the legal basis of this study is an important segment to be discussed. To develop informed policies, to support and provide more insights into policy making, the paper provides a constructive mechanism to enhance future policies (Fan et al., 2017), (Fan et al., 2019).

20 to 30% of total CO_2 emissions have been revealed to be associated with international trade (Zhang et al., 2020; WTO 2021). A similar observation by the UNEP (2023), includes the latest data and implies that economic actors are contributing immensely to the rise of harmful gasses. Wang et al., (2023), agree that another way in which production activities contribute to CO_2 emissions, is by the method of transportation through which commodities are being imported and exported through various stages in the value chain (Guedidi & Baghdadi, 2020), (Wang et al., 2019). (Najardeh et al.,2021), (Lin, B., & Sun, C. 2010), (Adlakha, 2023). Liu. et al., (2023) used China as an example to illustrate the level of emissions as production in GVCs increases. The authors develop a hypothesis and conclude that trading influences and the impact of emissions differ if 'green trade' is being practiced in the long run.

Hui Wang et al., (2020), report that China has been the largest emitter of CO_2 since 2006. By illustrating bilateral trade with the US (Dai et al., 2021), or by using a sample from other Asian countries (Assamoi et al., 2020), most academic papers focus has been on China. In this sense, China is the main manufacturing and production country (Bi. Huang, & Wang,2016), (Z.Yang 2022). However, from the perspective of the author, CO_2 emissions should be analyzed from a global viewpoint as it is a global challenge. A term coined from literature is 'decouple China from CO_2 emissions', China's participation in GVC intensely impacts its economy and CO_2 leakages (Espinosa-Gracia et al, 2023). Another study by (Hua et al.,2022) stated that China's economic participation in the GVC examined from 2000 to 2007 has revealed that firms produce intensive pollution. A structural decomposition analysis to measure the determinants from both sides of the spectrum; that is, production and consumption. From Wang's paper, it is seen that from 2007 to 2012 there was a decrease in emissions but it regained growth after the global financial crisis. It is argued that GVC is still the main cause of sustainability in China. (Hui Wang et al., 2021) (Yang et al.,2021), (Ferrarini et al., 2015), and (Wang et al., 2023). Other economies cited as common examples in literature are Brazil, Russia, the USA, and China, (Fan et al.,2019), (Qian et al., 2022).

Innovative ways through which global trade dynamics are changing have been illustrated in several previous literature that analyzed how the role of evolving technology is influencing GVCP to curb the effects of CO_2 emissions (Ali & Wang 2023), and (Moses et al., 2022) illustrate the same views saying that adoption of technology can contribute to cleaner production. (Q. Ma et al., (2022) supported the view that the usage of digital technologies can therefore enhance a cleaner environment. China is used as a case-in-point example and it is argued that digitalization of the economy should be further developed for economic growth to reach environmental sustainability. Liu et al. (2020) demonstrated that China's carbon emissions embodied in manufacturing exports outweigh their scale, and composition effects. (Hu et al., 2022), follow a similar pathway and illustrate how a green technological pathway can boost the use of cleaner production technologies in sustainable trade. (Wang et al., 2023), shared the same perspectives by saying that the adoption of technology is crucial for ecological trade. In a similar view, studies that cited China as an example investigate the effects of GVC and its technological impacts. However, it is argued that adopting cleaner production is not the main priority for industries in developing and undeveloped countries. Green technologies are inaccessible and industries are discouraged from investing due to the high cost of green technologies. Hence, to address this situation, it is imperative to strengthen policymaking and enforce strategies (Qi et al., 2020), (Li et al.,2023). The theoretical basis established refers to the theory of comparative advantage (Jing Wang,2019). The manufacturing sector is noted to release more emissions compared to the service sector free trade is expected to affect national output including developing countries moving toward pollution-intensive trade. Another way of looking at it is that trade may help reduce pollutants in developed countries as these economies are partly relocated to developing areas. A widely discussed theory by scholars is the theory of 'trade liberalization' or also known as 'trade openness' (Wang, Zhang, Li;2023). It is argued that the relationship between carbon emissions and trade liberalization has attracted the attention of scholars in recent years. The scholars illustrate that economies use different energy to create the same product, which hence, leads to different carbon emissions as countries provide the same quantity of product (Kou et al., 2023).

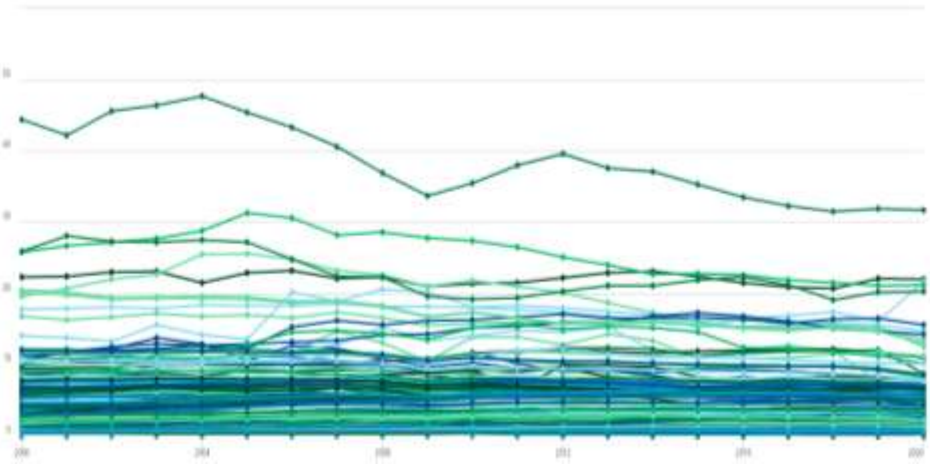

Figure 1: CO2 Emissions in Kt. Source: Word Bank Database.

What do previous studies reveal?

The impact of GVC participation on Gross Domestic Product (GDP), on CO_2 emissions has also been widely explored in previous research. Studies have focused on the effects of GVC participation on sustainable growth while omitting vital aspects of sustainability itself.

Meng et al. (2022) showed a correlation between GVC participation and CO_2. The study of Wang et al. (2019) assessed the impact of GVC participation on per capita CO_2 emissions. A panel data of 62 countries from 1995 to 2011 was used from an input-output database. An inverted-U relationship between GVC and CO_2 was found. A similar finding was derived from the study of Zheng et al., (2022). Bo Meng et al., (2018) conducted the study by analyzing value-added and CO_2 emissions in global production and trade networks among 41 economies in 35 sectors from 1995 to 2009. (Wang et al., 2019) revealed that there is a positive correlation between trade openness and CO_2 emissions. Adrián Espinosa-Gracia et al (2023) analyzed Inter-Country Input-Output tables (ICIO) for 66 countries and 45 industries and covered the period 1995 to 2018. The authors revealed that positions in GVCs are linked to lower global emissions, the effects of participation are dependent on trade openness, and increased competition in the trade leads to higher emissions. In 2002 and 2008 breaks were identified, and participation became significant from 2002 henceforth. Previous research focused on panel regression analysis, using data for CO_2 emissions of 63 countries and regions from 2005 to 2015 based on the World Bank data from 2005–2015, which was divided into high-income, upper-middle-income, lower-middle-income, and low-income. It was revealed that the average GVC participation extent of high-income countries was higher than others. The average per capita CO_2 emissions are found to increase as income levels increase. During 2008–2009 due to the financial crisis and recovery period in 2010–2011, it is demonstrated that GVC participation decreased after 2011. The study by Assamoii et al., 2020 covered the period 1995–2014 and employed both fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) methods. The findings revealed that higher participation in GVC leads to lower CO_2 emissions, while economic growth and energy consumption increase CO_2 emissions. The results also show a negative link between trade openness and CO_2 emissions. The paper of Zhong et al., (2021), posits an econometric panel data analysis to illustrate the impact of participation in GVCs on emissions being transferred through trade in 39 economies. It was found that as participation in GVCs increases, emissions through trade also rise. Xiaoming Ma et al., (2022) investigated GVC participation effects on carbon emissions by using the electro-optical equipment industry as an example. Major findings revealed stipulated that Asian countries have the highest participation rate in the GVC. Bo Meng et al., (2018) conducted the study by analyzing value-added and CO_2 emissions in global production and trade networks among 41 economies in 35 sectors from 1995 to 2009. The study of Jithin et al., 2023 revealed that the direction of participation in GVCs holds a degree of importance because forward participation has fluctuated on CO_2 emissions. It is explained that backward participation decreases CO_2 emissions in both developing and developed countries. (Jithin. P et al., 2023). Qian et al. (2022) revealed the effects of GVC participation on CO_2 emissions fluctuate as forward participation can enhance less pollution while backward participation can have negative consequences (Wang Y. et al., 2022). It is argued that GVC participation has positive effects when associated with development, and sustainability Wang et al. (2022), (Zhu et al., 2022).

A structural decomposition analysis (SDA) from an input-output table has been applied in this study as a tool to calculate participation from GVC (Wang et al., 2017a) (Wang et al., 2017a), (Hui Wang, 2022). Scale effect, technique spillover effect, and composition effect have been applied in the study of Wang et al., (2019). It is found that GVC participation has different impacts on CO_2 emissions across countries and industries.

The research of (Ben-David et al.,2018) highlighted that MNCs conduct industrial activities in countries with poor environmental laws. This results in increased economic activity, which damages the environment and raises concerns about unethical practices. Existing studies have assessed the impacts of GVC participation on GDP, trade openness, forward and backward analysis in participation has been demonstrated, how to calculate participation in GVC has been illustrated, the relationship between GVC participation and CO_2 emission in Asian countries and other large economic countries have been assessed and their results reflect analysis before the year 2018, concise methodological frameworks and graphical structure have been presented in previous studies to contribute to effective policymaking. In this perspective, there is a need to think about how to properly contribute to scientific research by critically analyzing uncovered dimensions related to sustainability. The argument that is demonstrated in this paper abides by the thinking that to foster sustainability, we cannot neglect the social aspect. To keep the results precise, and to be able to incorporate the social dimension of sustainability to bring forward effective policy formulations for the future, one measurement is used, Inequality by Gini Index. The values are measured from the data available by the World Bank Database. A further explanation of Inequality measured by the Gini Index is provided in the methodology section. Another measurement used is Green Energy, from the World Bank's Database, and its specification in this study is also provided in the methodology of the paper.

II. Methodology

Data source

The methodological approach applied in this study is a panel data analysis of 45 industries against 32 nations from Input-Output tables available on the World Bank's platform. Except for GVCP, the data for all the variables used has been obtained from Input-Output tables from the World Bank's World Development Indicators (WDI) for the years 2000 to 2020. The availability of data was checked against the variables during the years. CO_2 emissions, measured in Kilotons (Kt) are set as the dependent variable. The data for GVC Participation for each country and industry has been derived from the Export Decomposition Method by the OECD-ICIO database for the same timespan (2000 to 2020). CO_2 is the dependent variable and a three-dimensional equation is set as a measure of testing for independent variables. $Ci,t = C + \beta 1GVCPiH,t + \beta 2Control\ i,h,t + \sum i,h,t$equation 1

C*i*,t is the 2-dimensional dependent variable representing CO_2 emissions for the country *I* and the year. C is the constant. *β1GVCih, t* is the independent variable, consisting of country *I, h* represents industries and t represents time. The method applied in this paper is panel data regression on the first basis, followed by an endogeneity test, then a robustness check, after that a mechanism test is carried out, and lastly the paper includes a heterogeneity test. The above method of testing is designed to develop concise findings.

Control variables.

Inequality (Gini Index)

The measure of income or wealth inequality within a given population has not been tested in literature by social scientists in this field of study. The Gini Index serves as a crucial control variable by offering an understanding of the socio-economic aspect. Inequality as a control variable establishes precision and fills in gaps that remained unexplored from previous research works. By definition, sustainability should encompass the environment and society, and in this context, trade represents economic activity. Former research about this area failed to include any variable that can promote sustainable trade activities to decrease emissions by upholding the full structure of sustainable development. Gini Index into the analysis, the research aims to account for the influence of pre-existing income disparities on the relationship between global value chain participation and emissions. This control variable helps isolate the impact of GVC activities, ensuring that observed effects on inequality are not merely reflective of existing economic global disparities. Furthermore, the Inequality variable is pivotal in capturing the broader context within which emissions and global value chain participation interact. Countries or regions with higher inequality levels may experience distinct dynamics in the distribution of costs and benefits associated with GVC engagement, impacting both environmental and social outcomes. The Gini Index is integral to this research, providing a controlled lens through which the intricate connections between global value chain participation, emissions, and socio-economic inequality can be more accurately examined and interpreted.

Green Energy

The energy intensity level of primary energy is the ratio between energy supply and gross domestic product measured at purchasing power parity. Energy intensity is an indication of how much energy is used to produce one unit of economic output. A lower ratio indicates that less energy is used to produce one unit of output (World Bank, 2023)". The extent to which renewable and environmentally friendly energy sources are integrated into the production processes holds the potential to reveal several key insights. Green Energy as a control variable will contribute to enhancing interventions, policies, and regulations in steering industries toward eco-friendly practices within the context of global value chains. Investment in green technologies, as reflected in the Green Energy variable, can be indicative of technological innovation within industries. This innovation, driven by the pursuit of sustainability, not only contributes to emissions reduction but also enhances the competitiveness of industries in the global market. The Green Energy Variable serves as a proxy for the potential of industries to mitigate carbon emissions. Understanding the relationship between the level of green energy integration and carbon emissions is essential for formulating strategies aimed at achieving sustainable and low-carbon global value chains. Policymakers can utilize insights from the Green Energy variable to tailor strategies that encourage and incentivize industries to adopt greener practices. Similarly, businesses can gain a competitive advantage by aligning their global value chain participation with environmentally conscious approaches, meeting the increasing demand for sustainable and responsible production. The Green Energy Variable is expected to exhibit a negative correlation with carbon emissions within the framework of global value chain participation. Industries and countries with higher levels of green energy integration are anticipated to demonstrate lower carbon emissions per unit of production. This negative relationship suggests that as global value chains become more environmentally sustainable, they have the potential to contribute significantly to the reduction of carbon emissions on a global scale.

GVC Participation

To measure participation in GVCs an assessment of the share of value-added as contributed by multiple economies in the production process is illustrated by an export decomposition method. In this methodology, the decomposition is built upon an analysis of previous methods used by scholars. Regarding this study, the method used has been analyzed from the papers written by scholars, (Zhong et al., 2021), (Wang et al.,2017), (Wang et al., 2022). Value-added from each industrial actor or country also known as GDP by industry is decomposed to where it is consumed. From the study of (Wang et al., 2017a) a proposed decomposition framework including forward and backward industrial linkages to measure the degree of participation in GVCs has been included. Building up on this method, this paper uses this method to compute participation from GVC. From the method used by (Wang et al., 2017), scholars argue that a more "observational approach" in estimating a country's participation in GVCs. Hence, it is a widely acknowledged and used method for scholars to analyze the results of economic and environmental effects regarding participation in GVCs. Following from the structure provided by Wang 2017, the framework used in this paper is presented. (Zhong et al., 2021), (Wang et al.,2017), (Wang et al., 2022).$Va^{'} = \hat{V}BY = \underbrace{\hat{V}LY^{D}}_{(1)\hat{V}_D} + \underbrace{\hat{V}LY^{F}}_{(2)\hat{V}_RT} + \underbrace{\hat{V}LY^{F}LY^{D}}_{(3a)\hat{V}_GVC_S} + \underbrace{\hat{V}LY^{F}(BY - LY^{D})}_{(3b)\hat{V}_GVC_C}$ (1)

Decomposition method:

After analyzing the methods and models used by previously published materials on this topic in the literature, it was seen that several studies have used variations of the decomposition method to analyze different aspects of CO_2 emissions, energy intensity, and environmental sustainability. In this study, the decomposition method applied has culminated from the research of Wang et al. (2018) notably. The research of Wang, 2018, used an index decomposition analysis approach to assess the role of international trade in global CO_2 emissions. The study focused on the trade patterns and their impacts on global emissions. As this study includes a multiregional array of data, it is seen that the decomposition model applied matches that from the study of Wang et al. (2017b). From the method designed by Wang et al, 2017, a multi-regional structural decomposition analysis was developed (MR-SDA) model to examine emission intensity changes in global economies. Hence, building up on the decomposition analysis of (Wang et al, 2018) and (Wang et al., 2017), this study further demonstrates new pathways by addressing examined research gaps. The expression for GVCs forward participation is:

$$GVC\_Pat\_F = \frac{V\_GVC\_S + V\_GVC\_C}{Vd} \quad (2)$$

Vd refers to the added value domestically produced and consumed.

V_RT includes domestic value-added and, hence, embodied in final product exports.

V_GVC_S represents domestic value-added embodied to a specific country sector. The value refers to intermediate exports referring to the direct importing country's production consumed in that specific country.

V_GVC_C refers to local factors emerging from a country's sector that are included in its intermediate exports, hence, and consumed by a direct importing country for production exports to other countries.

Va represents Value-added, describing domestic value-added generated from sectors in the country.

GVC activities by downstream economic actors share the country-specific sector to total value added. Final goods production of the country is also decomposed through where the value-added Equation3

$$Y' = VB\hat{Y} = \underbrace{VL\hat{Y}^D}_{(1)Y\_D} + \underbrace{VL\hat{Y}^F}_{(2)Y\_RT} + \underbrace{VL\hat{Y}^F L\hat{Y}^D}_{(3a)Y\_GVC\_S} + \underbrace{VLA^F(B\hat{Y} - L\hat{Y}^D)}_{(3b)Y\_GVC\_C} \quad (3)$$

The equation to illustrate backward participation, Equation4:

$$GVC_P at_b = \frac{Y_G VC_S + Y_G VC_C}{Y'} \quad (4)$$

From the equation, *Y_D* refers to the domestic value-added in domestic final products. *Y_RT* is domestic value-added in final exports. *Y_GVC_S* shows foreign value added in an economic sector that is imported directly from partner countries. *Y_GVC_C* represents either returning domestic value-added or foreign value-added embodied through intermediate imports used by the local countries for the production of final products. It could be either domestic use or exports. Y′ shows the production of the final goods and services. It illustrates the value added that is included in GVC activities by upstream firms (Wang et al., 2017b). The position of GVCs is illustrated in the decomposition model of (Wang et al., 2017b), hence defining it as the ratio of two GVCs production lengths. The resulting equation is as follows: Equation 5, 6 and 7:

$$Plv\_GVC = GVC = \frac{Xv\_GVC}{V\_GVC} \quad (5)$$

$$Ply_G VC = \frac{Xy_G VC}{Y_G VC} \quad (6)$$

$$GVC_P s = \frac{Plv_G VC}{Ply_G VC} \quad (7)$$

Forward GVC linkages in GVC production chain length, denoted as *Plv_GVC* show the average length of production within the country's industrial sector at the end of the value chain. It is calculated as the ratio of the domestic value-added linked with the GVCs to the total output resulted is thus generated. *V_GVC* represents the domestic value-added culminated by the export of intermediate products. *Xv_GVC* shows the total output by value-added resulting from the export of intermediate products. The backward-linked GVCs production chain length *Ply_GVC* shows the distance from inputs in other countries to the final product of an industrial sector in the country. It also measures the average production length of foreign value added embodied in intermediate imports from the first time as a major input to the production process as a final product. From the equation, *Y_GVC* is the foreign value-added of the import of intermediate products and *Xy_GVC* is the final output created in the country by the foreign value-added of intermediate products imported (Wang et al., 2017b), (Qian et al.,2022)

Table1: list of variables.

List of variables	Measurement	Source
FGVCP	Share of country's domestic value added that enters as an intermediate input in the value-added exported by other countries' organization	WDI
BGVCP	share of foreign value added used in a country's exports	WDI
GVCP	Global Value Chain Participation	WDI
CO_2 emissions	Kilotons (Kt)	WDI
Inequality	Gini Index	WDI
Green Energy	The energy intensity level of primary energy (MJ/$2017 PPP GDP)	WDI

III. Results and Discussion

Descriptive statistics

Table 2 below shows an understanding of the tendency of relevant variables, dispersion, and distribution.

Table 2: Descriptive statistics showing the key variables under examination.

Variable	Obs	Mean	Std. dev.	Min	Max
Forward	3,882	0.1425	0.07188	0.00137	0.5482069
Backward	3,882	0.14228	0.08943	0.00554	0.5279512
GVC participation	3,882	0.28479	0.09832	0.04157	0.578395
CO_2emission	3,779	183291	1369001	-20.552	2.17E+07
Inequality	1,649	87.7013	47.2644	6.4	428.7255
Green Energy	840	144.341	96.396	12.69	678.8171

As shown in Table 1 above, the average forward and backward participation in GVCs is 0.1425 and 0.14228, indicating a moderate degree of participation. The combined forward and backward dimensions are reflected in GVC participation, which has a mean of 0.28479. The range of GVC involvement is wide, with a low of 0.04157 and a high of 0.578395, indicating significant variation across countries. The average carbon emissions are 183,291, with a standard deviation of 1,369,001, indicating significant variability in the environmental impacts. With a mean of 87.7013, inequality demonstrates differences in income distribution among the selected nations. With a mean of 144.341, the green energy variable represents the average level of ecologically friendly energy use.

Correlation result

Table 3 shows the correlation data result for the variables used in the study. The result helps in determining the significant interrelationships among the study's primary factors. As shown in the table below, Global Value Chains (GVC) participation both forward and backward has a weak negative association (-0.1825). Based on these findings, nations that are more active in the forward dimension of GVCs are less active in the backward dimension, and the opposite is also a fact.

Table 3: Correlation result

	Forward	**Backward**	**GVCpar~n**	**CO_2emi~n**	**Inequa~y**	**GreenE~y**
Forward	1					
Backward	-0.1825	1				
GVC participation	0.8534	0.3567	1			
CO_2emission	-0.3017	0.2155	-0.1725	1		
Inequality	0.1643	-0.4826	-0.0998	0.2799	1	
Green Energy	0.0246	0.3631	0.2159	-0.1129	-0.2911	1

The strong and positive correlation (0.8534) found between forward GVC participation and CO_2 emissions is crucial. Carbon emissions from export products are projected to rise in nations that actively participate in the forward parts of global value chains, according to this strong correlation. There may be a trade-off between economic involvement in GVCs and environmental sustainability, as this research highlights the environmental consequences of active participation in certain aspects of global production networks.

In addition, there appears to be a moderate negative correlation between inequality and backward GVC participation (r=-0.4826). Therefore, economic inequality decreases as countries' backward participation in GVCs increases. Considering the distributional features within participating countries, this relationship highlights how GVCs can contribute to more equal economic arrangements. The forward and reverse GVC participation levels positively correlate with carbon emissions.

Density Estimate plot.

Many practitioners believe that a normal quantile plot provides a more reliable means of checking the normality of residuals. Kernel density estimators (KDEs) as shown in Figure 1 below. derived from the "number of components", observations are equivalent to adding up the values of an equal number of miniature distributions, each based on a sample. (Ma et al., 2022).

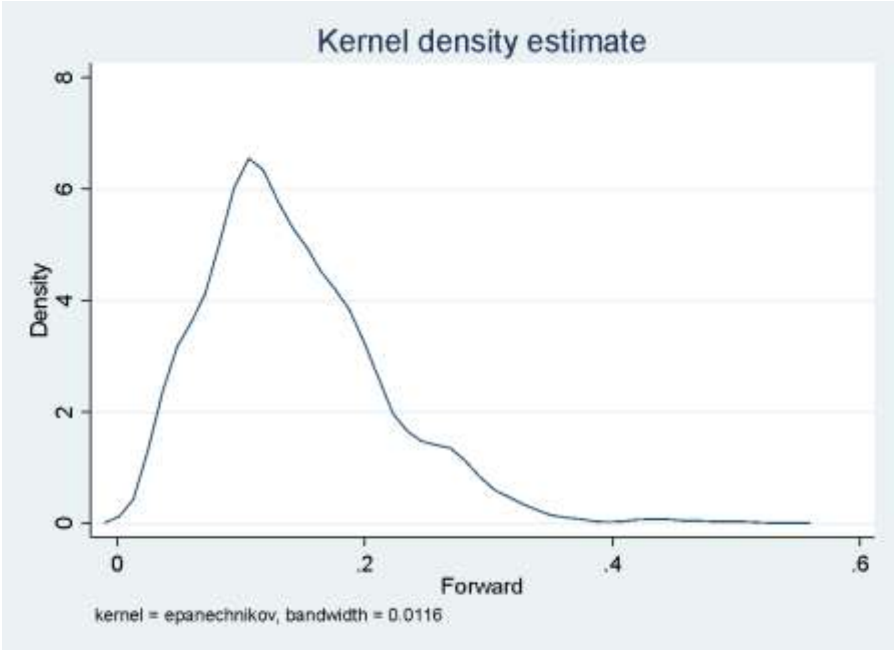

Figure 1: K-density plot of forward variable

The kernel density plot for the variable "Backward" shows a left-skewed distribution, indicating that most observations have lower values, with a tail extending higher. This plot's leftward tilt indicates a concentration of countries with lower levels of backward participation in Global Value Chains (GVCs), while fewer nations have higher levels of engagement in the backward dimension see the figure below.

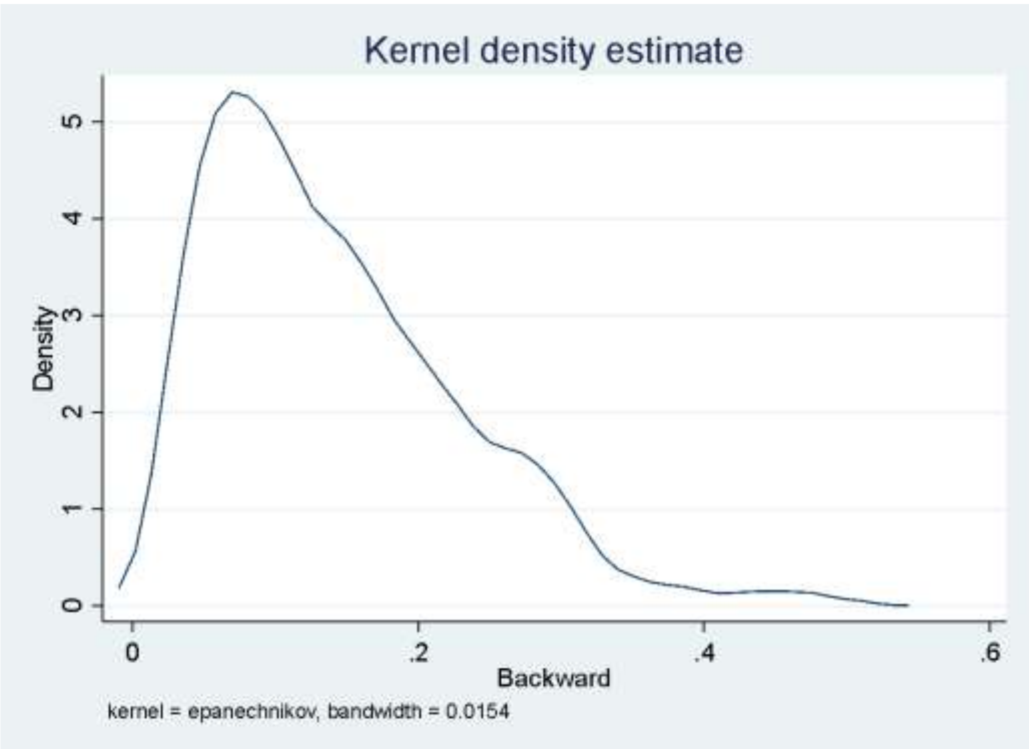

Figure 2: K-density for Backward plot

The peak of the density curve in a left-skewed distribution is to the right, indicating the mode or most frequently occurring values. (Liu and Zhao, 2021; Deqian et al., 2021; Huang et al., 2022). A significant number of industries have lower participation in GVC backward activities. The elongated tail on the left side of the curve indicates that fewer countries have relatively higher levels of backward participation.

Countries with lower backward participation may play a more specialized role in downstream activities like the manufacturing process's final assembly or distribution stages (Zhao et al., 2023). On the other hand, those with higher backward participation may be more involved in upstream activities, such as providing components or inputs to the global production network.

Baseline Regression model

Table 4 presents the results of the baseline regression model, employing Ordinary Least Squares (OLS), Fixed Effects, and Random Effects methods to explore the relationship between CO_2 emissions and independent variables used in this study including Forward GVC participation, GVC participation, Inequality, Green Energy, and Backward GVC participation.

Table 4: Baseline Regression model result

	OLS	**Fixed effect**	**Random effect**
VARIABLES	**CO_2 emission**	**CO_2 emission**	**CO_2 emission**
Forward	-2475016.823***	1300708.248*	-62,996.959
	(315,717.264)	(715,248.792)	(283,467.801)
Backward = o,	-		
GVC participation	1804953.797***		
	(302,404.214)		
Inequality	13,900.188***	15,832.051***	13,912.563***
	(1,989.317)	(2,933.721)	(2,610.306)
Green Energy	-281.983*	-135.260	-29.155
	(161.519)	(228.009)	(204.598)
Backward		754,244.522	877,955.619**
		(516,506.389)	(418,860.871)
GVC participation = o,		-	-
Constant	-410,950.316***	-667,307.524***	-451,177.852***
	(90,308.719)	(159,037.899)	(121,203.587)
Observations	169	169	169
R-squared	0.345	0.176	
Number of Indu		17	17
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1			

The OLS results in Table 4 above show important explanatory variable coefficients. It is worth mentioning that the Forward GVC participation has a negative coefficient of -2,475,016.823. This means that when forward participation increases, the CO_2 emissions decrease significantly. Consistent with earlier studies, the regression results demonstrate that the carbon emissions of these goods rise as the amount of forward and backward GVC participation increases (Column 3 of Table 3) Zhang et al. (2023) and Xiao et al. (2020).

Similarly, the coefficient for GVC participation is 1,804,953.797, which is statistically significant and suggests that greater CO_2 emissions are associated with more GVC involvement. The coefficient of 13,900.188 between inequality and CO_2 emissions highlights the positive relationship between the two variables, indicating that greater economic inequality within a nation is associated with higher CO_2 emissions. Green Energy's negative coefficient of -281.983 indicates a correlation between increased usage of green energy and decreased CO_2 emissions. In this equation, -410,950.316 is the constant term or intercept.

Controls for unobserved industry-level heterogeneity are introduced by the Fixed Effects and Random Effects models. After considering industry-specific factors, the relationship between forward participation and CO_2 emissions is still evident in the Fixed Effects model, where the coefficient for Forward GVC participation is still negative and statistically significant. The carbon emissions in exports resulting from the forward embedding pattern are noticeably lower than those of the backward embedding pattern, as indicated by comparing the forward and backward participation coefficients (0.094 < 0.595).

Notably, the coefficient for Forward GVC participation becomes statistically insignificant when industry-specific random effects are incorporated into the Random Effects model. The findings reveal that most sectors require substantial capital and technological equipment investments, and their production processes lead to environmental pollution.

Both the Fixed Effects and Random Effects models reveal a positive and statistically significant association between CO_2 emissions and Backward GVC participation when considered an independent variable.

The domestic input in developed economies could be more environmentally friendly and cleaner than imported goods due to their use of greener production technologies (Wang et al., 2021), which would improve environmental quality.

Mechanism Test

Table 5 below displays a model that incorporates a set of dummy variables that include GVC participation, Forward GVC participation, Inequality, and Green Energy, for each year between 2016 and 2020. Column 1 displays the outcomes of the initial stage of estimation, which reveals that GVC's forward and backward participation experienced a notable negative impact following the financial crisis. A similar finding was illustrated from previous research as illustrated in the literature. The results show that developing nations may be able to absorb advanced green technology by embedding in GVC. Column 2 shows that GVC forward participation has a significant positive effect on the scale of product exports. Nevertheless, there will be no noticeable reversal effect.

Table 5: Mechanism Test result

	(1)	(2)
VARIABLES	**CO_2 emission**	**CO_2 emission**
GVC participation	2.572***	2.509**
	(7.576)	(9.476)
Forward	-1.781	-1.781**
	(853,502.735)	(441,631.736)
Backward = o,	-	-
Inequality	18,046.361***	18,046.361**
	(2,762.653)	(6,756.950)
Green Energy	-35.935	-35.935
	(212.988)	(151.929)
	(54,910.100)	(76,347.997)
Year = 2016	-181,364.313***	-181,364.313**
	(55,467.653)	(76,920.566)
Year = 2017	-186,548.040***	-186,548.040*
	(59,224.891)	(88,338.181)
Year = 2018	-219,418.751***	-219,418.751**
	(58,786.642)	(92,399.836)
Year = 2019	-187,777.643***	-187,777.643**
	(58,374.258)	(82,257.445)
Year = 2020	-141,693.123**	-141,693.123*
	(58,450.276)	(76,833.369)
Constant	-823,142.982***	-823,142.982**
	(153,303.339)	(331,026.942)
R-squared	0.425	0.425
Number of Industries	17	17
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1		

This research plays a crucial role in emerging digital economy-related social and economic development fields, such as carbon surge, carbon neutrality, and organic incorporation and cooperation among firms involved in global value chains (GVCs). GVC embedment will play to the energy conservation, structure, and transfer effects and greatly contribute to achieving the carbon emissions reduction target. It will also emphasize the positive relationship between GVC involvement and carbon emissions. This aligns with the earlier findings from the baseline regression model, which aimed to reduce energy consumption intensity, optimize energy consumption structure, and strengthen carbon emissions transfer.

Still, while forward GVC participation isn't statistically significant in Column 1, it becomes so at the 5% level in Column 2. Reducing GVC carbon emissions should be the primary focus of new energy solutions. Interactions between information globalization and GVCs not only lead to the most remarkable drops in energy consumption but also hasten the digital transformation of sectors with high energy consumption, like transportation, by distributing production activities and improving energy efficiency.

Robust Test

Table 6: Robust test result

	Model (1)	Model (2)
VARIABLES	**CO_2 emission**	**CO_2emission**
GVC participation	1.248	-6.959
	-1.07	-1.773
Inequality	754,244.522	877,955.619*
	(678,488.713)	(453,595.096)
Green Energy	15,832.051	13,912.563
	(10,286.852)	(9,072.111)

Backward	-135.260	-29.155
	(160.195)	(127.033)
Constant	-667,307.524	-451,177.852
	(508,139.592)	(341,380.882)
AIC	4385.816	
BIC	4401.466	
Industry effect	Yes	Yes
Time effect	Yes	Yes
Control Variable	Yes	Yes
Country effect	Yes	Yes
R-squared	0.345	0.176
Fixed and Random effect		
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1		

Table 6 shows the outcomes of the robust test, which uses additional controls (fixed and random effects, industry and time effects, and country-specific controls) to investigate the baseline regression model's sensitivity. Whether the dependent variables are replaced, or the sample is divided into low, medium, and high groups, models 1–2 demonstrate that GVC embedding significantly suppresses the CO_2 emission; this suppressive effect increases with the increasing degree of GVC embedding. In Model 1, the GVC participation coefficient of 1.248 is not significantly different from zero. On the other hand, the coefficient becomes -6.959 and reaches statistical significance at the 10% level in Model 2, which includes more controls. The findings of this study corroborate those of previous research, such as (Yan et al.,2020) and (Chen et al., 2022).

IV. Conclusion

This research has demonstrated the effects of GVC participation on emissions from 2000 to 2020 by using a larger dataset available from the World Bank database. The participation of countries in GVCs has significant implications for emissions and economic development. The findings from previous studies have been discussed. To some extent, values regarding emissions and participation tend to reflect similar observations. This research sets out to reveal the importance of examining neglected dimensions of sustainability in enforcing sustainable trade. Emissions are measured against the dependent variable GVC Participation. The calculation of participation results from the decomposition analysis demonstrated from previous literature. Inequality is measured by the Gini Index and Green Energy represents the independent variable. Backward participation shows a left-skewed distribution in the plot. Forward GVC participation has a negative coefficient of -2,475,016.823 when tested with Ordinary Least Squares. The coefficient for GVC participation is 1,804,953.797and it is found that the greater the CO_2 emissions the more it is associated with more GVC involvement. The coefficient of 13,900.188 between inequality and CO_2 emissions depicts a commendable relationship between the two variables. Green Energy holds a negative coefficient of -281.983 revealing a correlation between increased application of green energy and decreased CO_2 emissions. Studies have mentioned about adoption of cleaner technologies in production, carbon-reduction mechanisms, and investments in innovation and development to tackle the issue of carbon emissions in value chains. In addition to this, the promotion of circular economy principles can contribute to protecting the environment. Policymakers can enforce laws and legislation, and developments in international law can be an effective instrument. This study was designed to include the maximum possibilities of data for the variables according to the recent years available for the countries listed in the World Bank database. Data for every sector cannot be obtained. The fact that in this research it is put forward that trade is becoming more and more interdependent be it between small economies or larger economic actors, most of the countries are binding with the principles of international law. Hence, a segmental analysis is not appropriate in this context. Another insight derived from the study is that enforcing good governance principles will encourage accountability, ethical practices, and transparency. This in turn will help to foster sustainable trade.

V. Limitations and future suggestions.

This study is not without limitations and it is not possible to research all the dimensions through one specific study. Hence, this section can also be used by future research targets in this area. Firstly, there is a need to include other socio-economic measurements to produce more research about all the dimensions as understood by the sustainability term. Secondly, studies published in this area mostly investigate large economies and the

Asian geographical part of the world. It can be understood that researchers know that in larger economies there may be more emission leakages. However, future studies involving other parts of the world will provide variation in this research area. As presented in this research, through the basis of international law, and involvement of trade interconnectedness, a precise segment of the world would not be appropriate for this study. Lastly, there have been limitations in the availability of data involving emissions released by sector-specific actors.

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